Power for the Soldier: Small Engine Prospects

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Why are we here ?

Perspective on Small Engines
(emphasis on 4-cycle spark ignition)

- Big picture on power and fuel choices
- Real progress
- Lower weight in smaller sizes
- Good performance on jet fuels
- More than competitive
- Practical

Best Practice - Best Guesses

Engine Type	Best Efficiency?
Big ship diesel	46 (%)
Coal-fired steam plant	44
Truck diesel	43
Modern car, gasoline	36
Fancy gas turbine, 2,000 hp Abrams tank	35
Honda 1000W generator	30
Honda string trimmer, 1 hp, 4-cycle	25
Model aircraft, jet fuel, 1/2 hp, 4-cycle	20
Gas turbine APU, simple cycle, 100 kW	15
String trimmer, 1 hp, 2-cycle	11
Fuel Cells, portable:	
H2	40

Fuels

Type	Heat of Combustion Wh/kg	Energy Density Wh/l	Delivered Wh/kg with Container
Lithium Primary Battery	11,800	6,300	400
Hydrogen 9000 psi glass microspheres	33,000	1,840	1,320*
Methanol 10% can	5,470	4,320	4,920
JP-8 10% can	11,900	9,640	10,700

*SAE 1999-01-2726, Patil & Jacobs, 4% H_2

The last Army owned small gasoline engine.

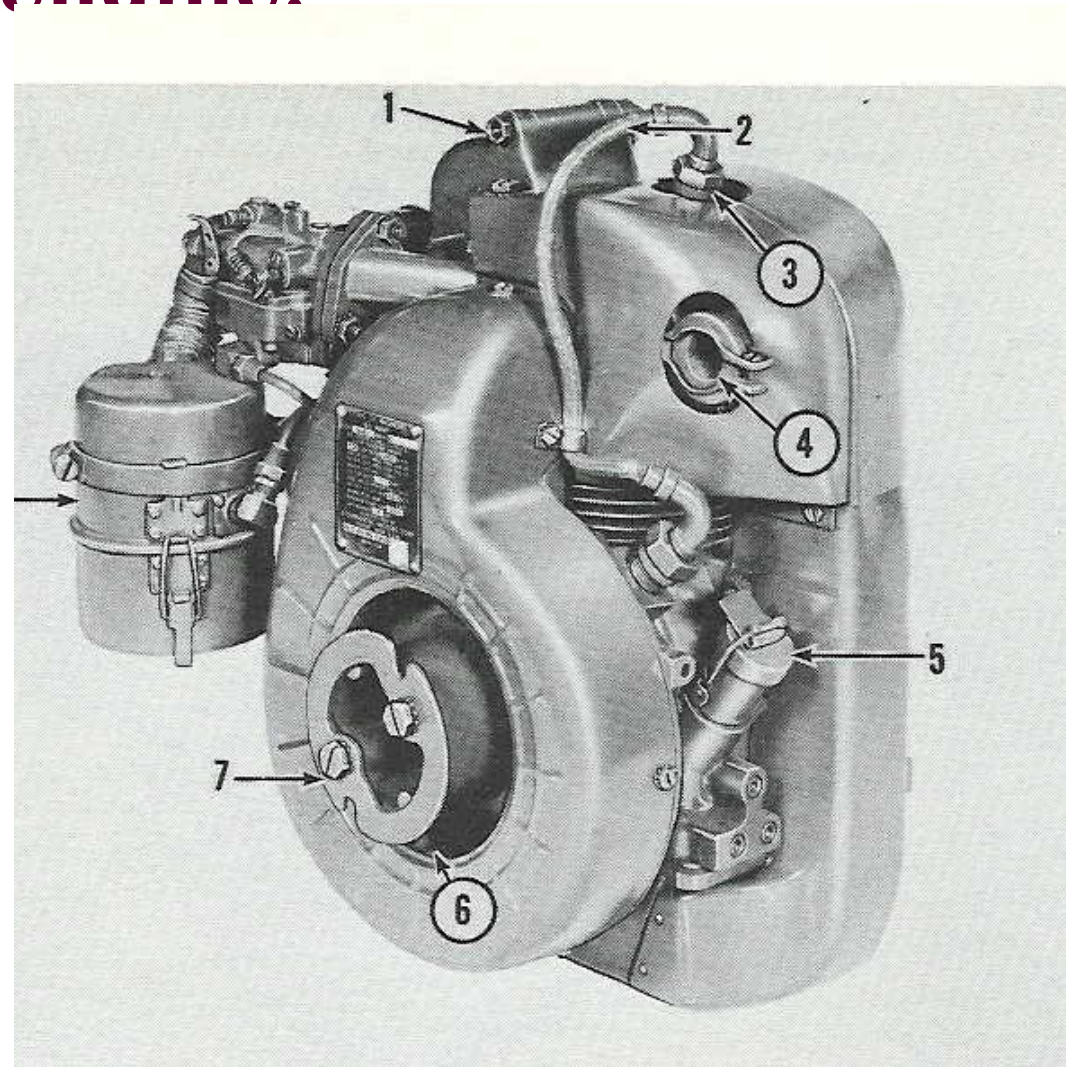
16 cubic inch single

1.5 hp @3,600 rpm

40 pounds!

1960 US Army 1A08

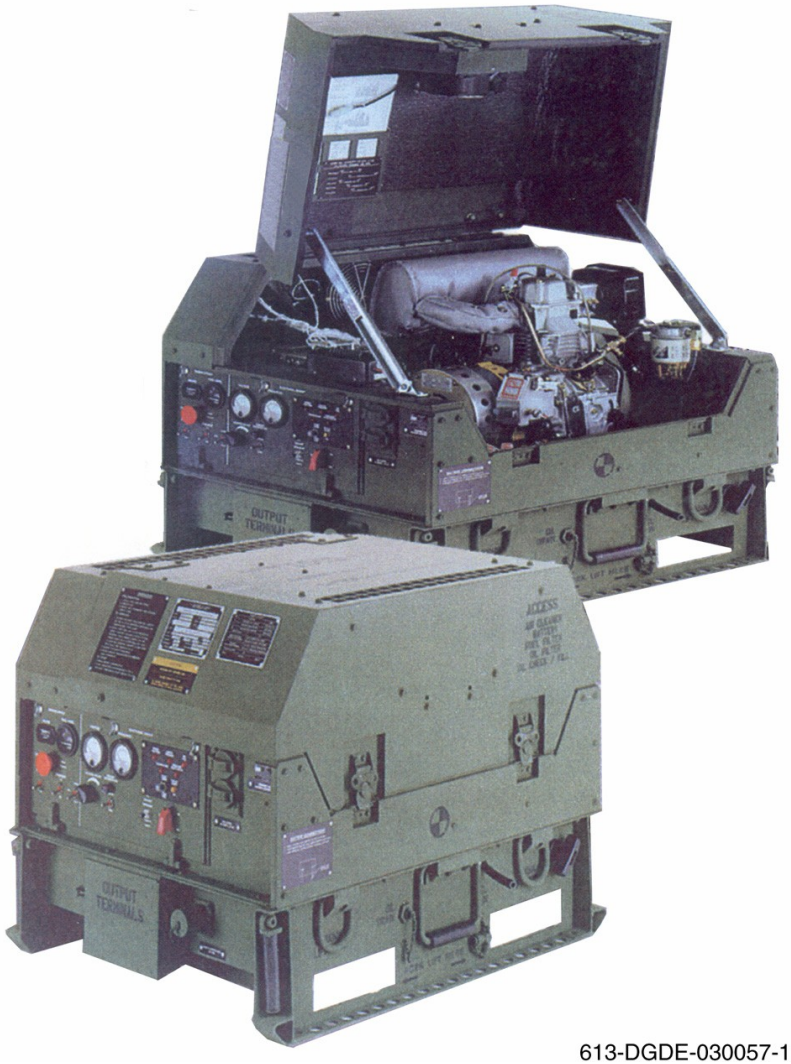
(runs well on JP-4)



Current Military Diesel Gen

Fermont Co. conversion of a Yanmar commercial diesel

3 kW, 123 kg for 25 W/kg



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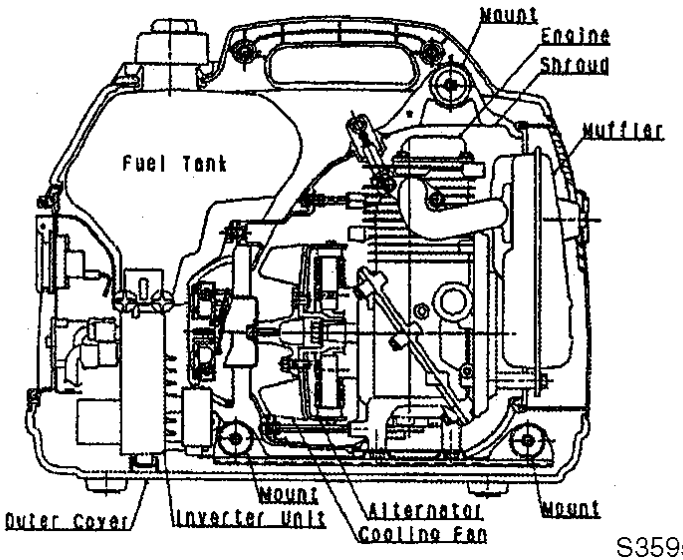
HONDA
FG100
HONDA
EU1000i
HONDA
For this, Santa deserves
extra cookies.

1998 Product Example

Honda 1,000 W Gasoline Fueled "All Electronic" Control and Power Conversion



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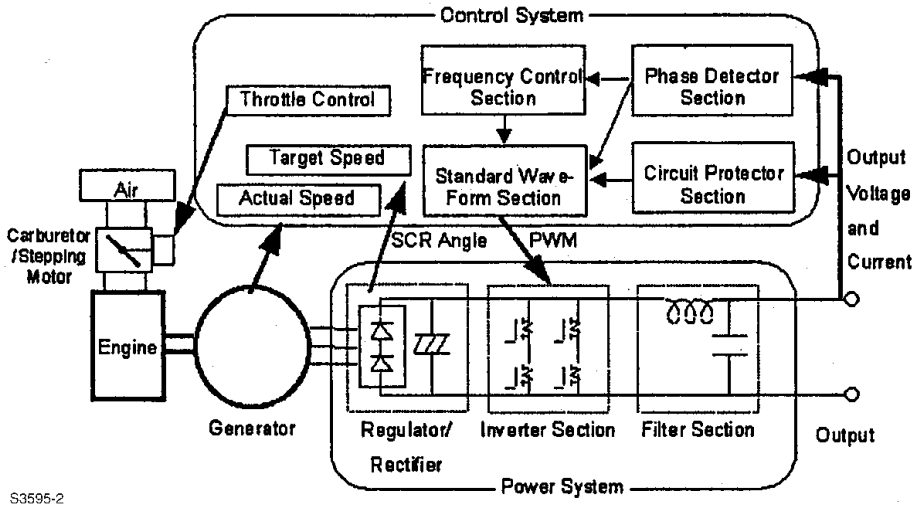
- 900 W continuous power
- 58 dB at 7m, 6000rpm
- 13 kg w/o fuel
- Engine only efficiency estimated at 30 percent
- Overall efficiency estimated at 25 percent



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Similar Piston Engines
4-cycle spark ignition

- "Photographic" scale of all dimensions
- Proportions remain the same
  - s =stroke (in.)
  - b =bore (in.)
  - $\mathring{s}$ =piston speed (fpm)
  - $\bar{p}$ ="bmep" - break mean effective pressure, (psi) (calculated average pressure on piston during power stroke required to produce measured torque)

Similar Piston Engines *(continued)*

- For now, say bore = stroke (square)
  A_p = piston area (in^2) = 1/4 π b^2 ~ s^2
  - Power limited by airflow (15 x fuel flow), $\dot{w}_{air}$
  - $\dot{w}_{air}$ ideal = 1/4 $\dot{s}$ A_p (four cycle) $\dot{s}$ ~ s^2•
  - Real air flow limited by intake valve pressure losses determined primarily by piston speed
  - Similar engines have same gas velocities and volumetric efficiencies at same piston speed leading to same $\bar{p}$ versus $\dot{s}$

Similar Piston Engines (*continued*)

Using stroke, s as reference dimension

Power: hp = $\frac{\bar{p} A_p \dot{s}}{132{,}000}$ (four cycle engine)

For given $\dot{s}$ that also fixes $\bar{p}$

Hp ~ A_p ~ s^2 (b/s assumed constant)

D, displacement ~ s^3

hp/D ~ s^2/s^3 ~ $1/s$

Rpm at constant $\dot{s}$ ~ $1/s$

Wall thickness ~ $1/s$

Thermal resistance ~ $1/s$

Pressure stress ~ $\frac{\bar{p} r}{t}$ ~ s/s = constant

Weight ~ s^3

hp/lb ~ s^2/s^3 ~ $1/s$

Similar Piston Engines *(continued)*

- **Dynamics**
  - Piston acceleration, $a \sim v^2/r \sim {}^2/s \sim 1/s$
  - Piston weight, $w \sim s^3$
  - Piston inertia $\sim aw \sim s^3/s \sim s^2$ $\ddot{s}$
  - Bearing area $\sim s^2$
  - Bearing pressure $\sim$ inertia/area $\sim s^2/s^2 = 1$
- **Noise**
  - dB = f(10log power) i.e., 1/10 power = -10dB

Smaller engines have higher power to weight ratios

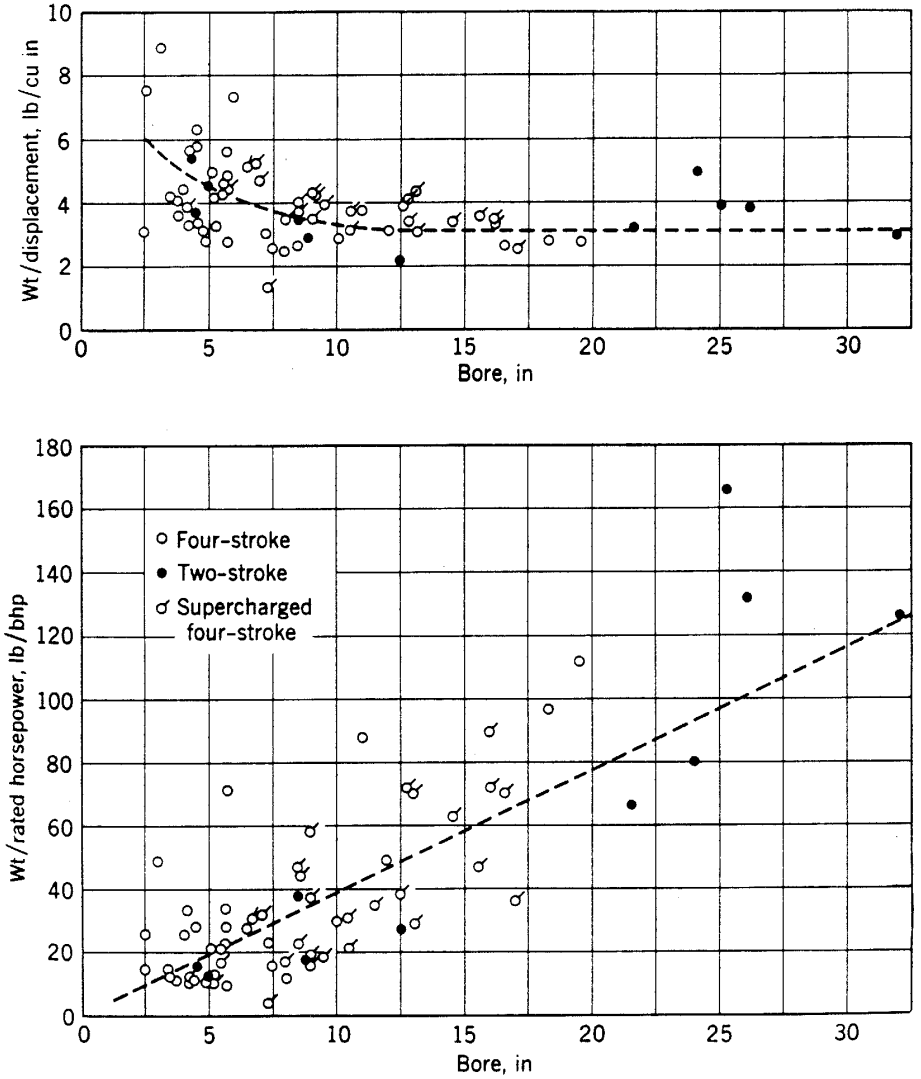
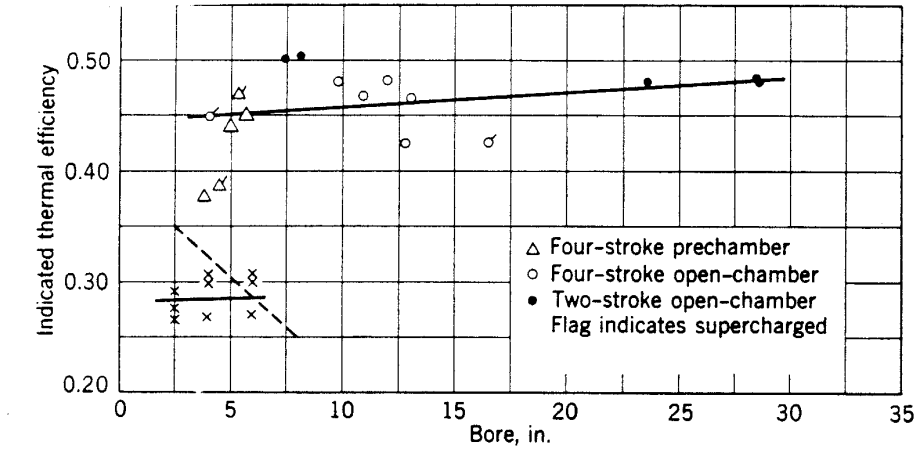


Fig 11-5. Weight per unit displacement and weight per brake horsepower vs bore of Diesel engines. (Data from *Diesel Power* April 1954.)

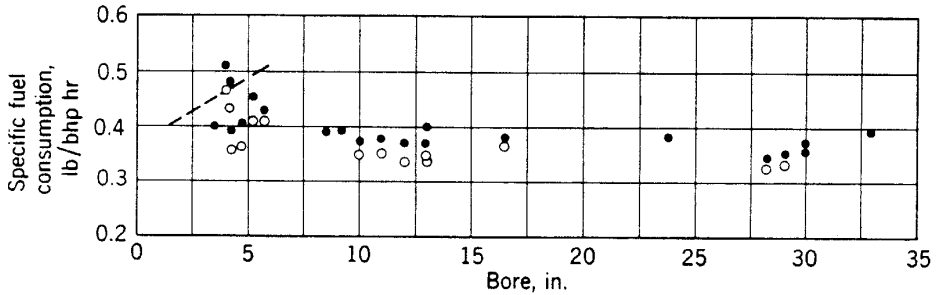
Small engines can be efficient



△ ○ • Diesel engines at 0.60 × chemically correct fuel-air ratio, from manufacturer's performance data, 1949

× MIT similar spark-ignition engines at $F_R = 1.1$, $r = 5.74$ (Lobdell and Clark, ref 11.21)

– – – MIT similar spark-ignition engines at knock-limited compression ratio (ref 11.44)



• Diesel engines at rated output

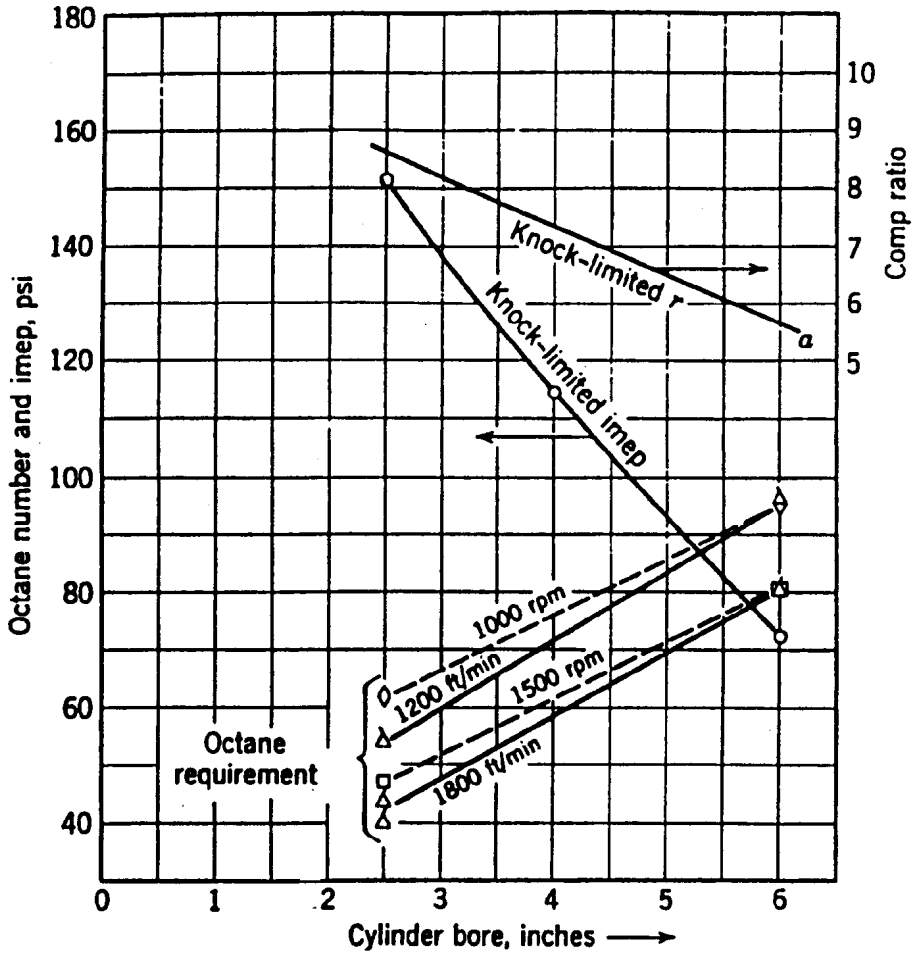
○ Diesel engines at best fuel economy

– – – MIT similar spark-ignition engines at knock-limited compression ratio (ref 11.4

(b)

Fig 11-6. Efficiency and economy vs cylinder bore.

Influence of Cylinder Size on Engine Performance



Symbol	Comp ratio	Fuel	Piston speed	Inlet temp °F	rpm	Source
a	var	*	1500	180	var	ref 11.44
○	5.74	72 ON	1200	180	var	ref 11.23
△	5.74	var	1200	160	var	ref 11.43
△	5.74	var	1800	160	var	
□	5.74	var	var	160	1000	
◇	5.74	var	var	160	1500	

* 82.5 ON at S = 1000
71 ON at S = 2000 fpm

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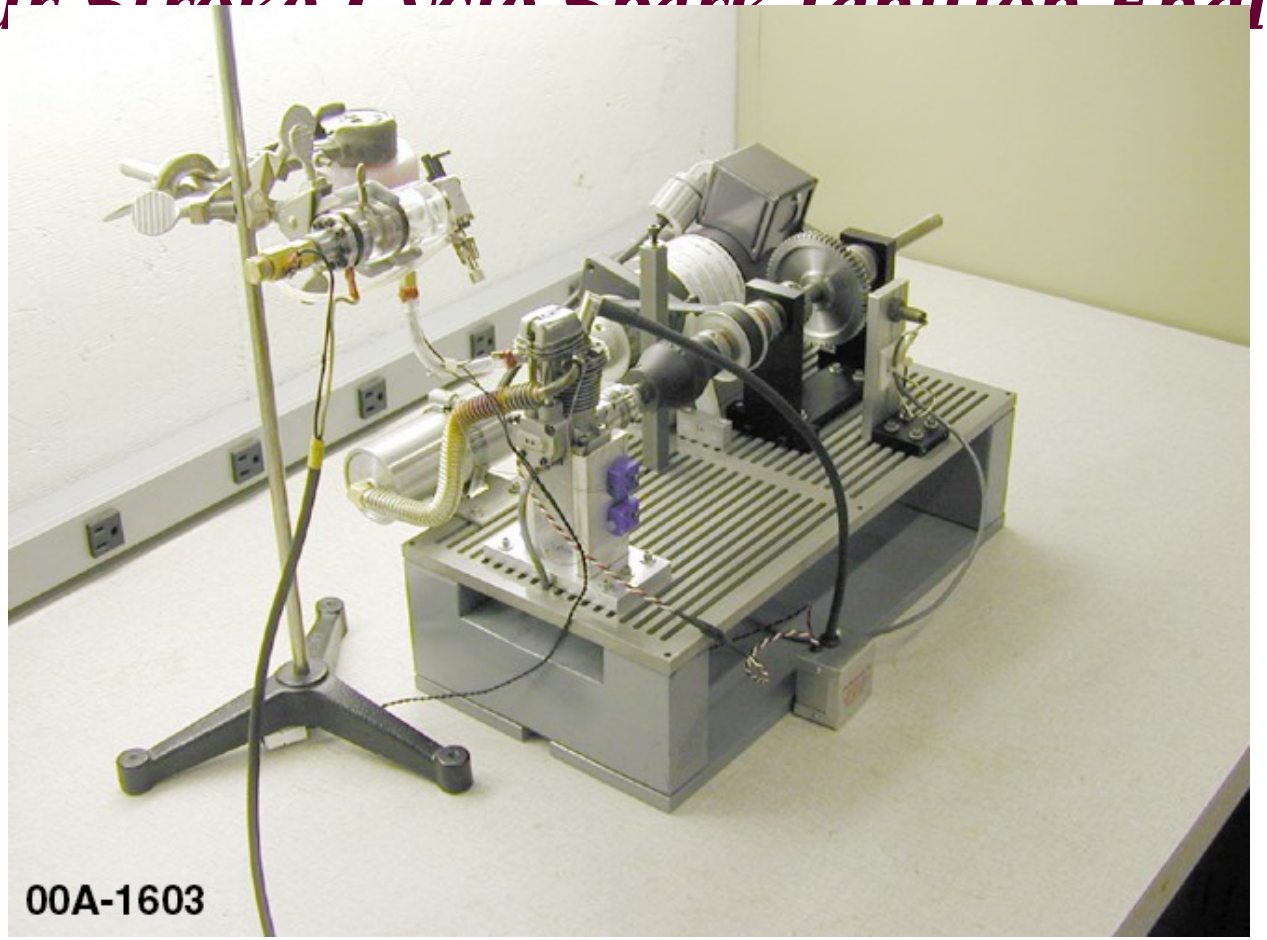
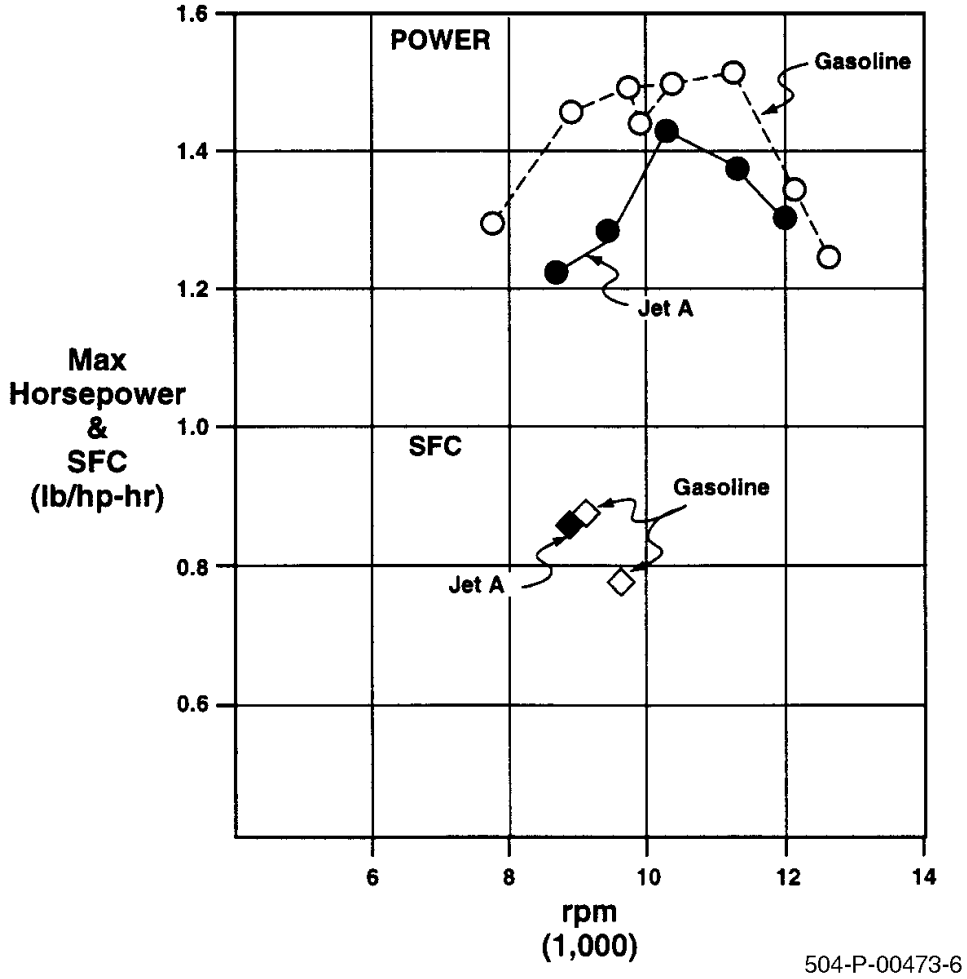
Small Engine Test Rig

For JP-8 Use in a 0.41 Cubic Inch Displacement Enya 41 Four Stroke Cycle Spark Ignition Engine

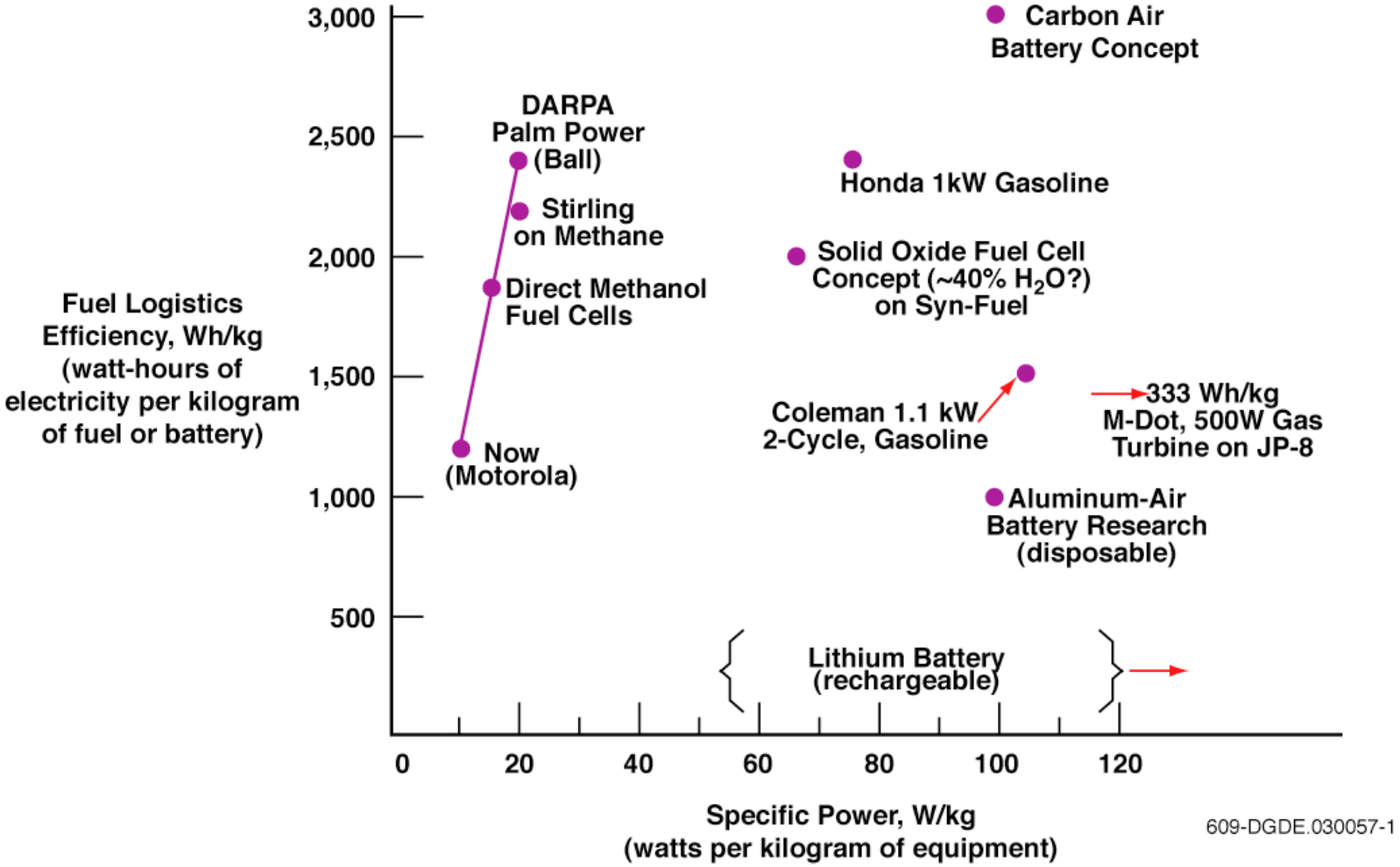


Foster-Miller Small Engine Test Dynamometer and Freezer

Foster-Miller/Ft. Belvoir OS-120 Gasoline and Jet A Data



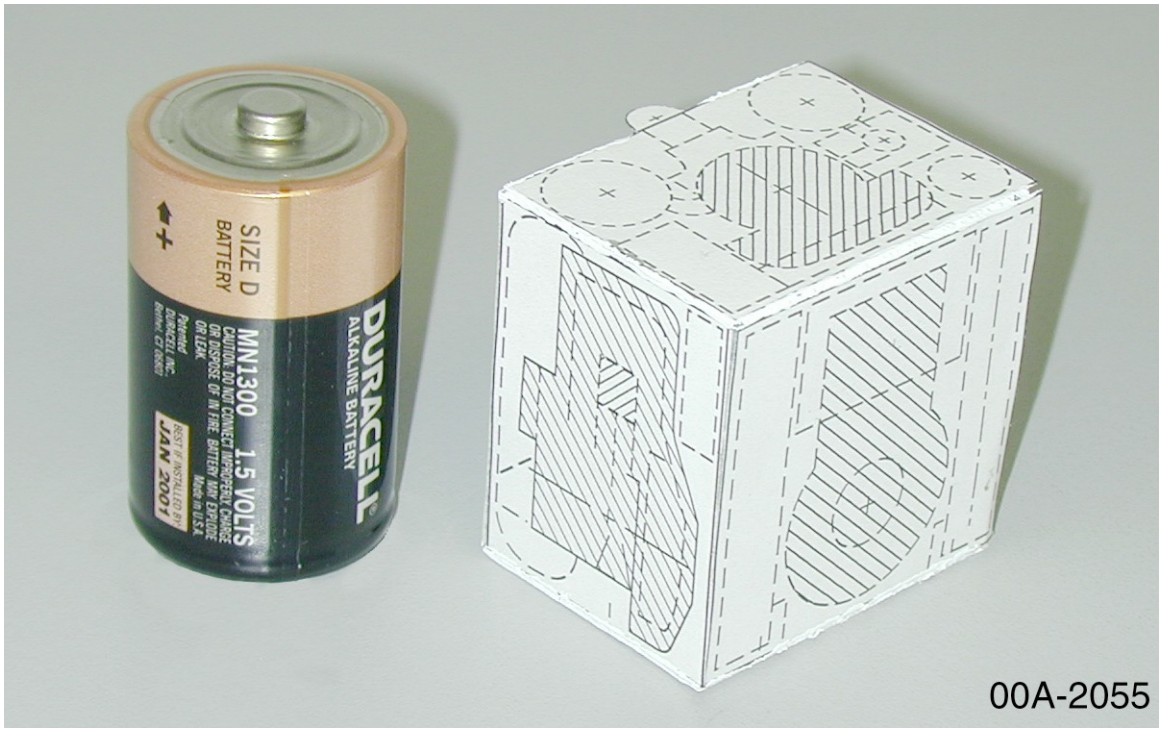
Portable Electric Power Systems, 20W-1,000W



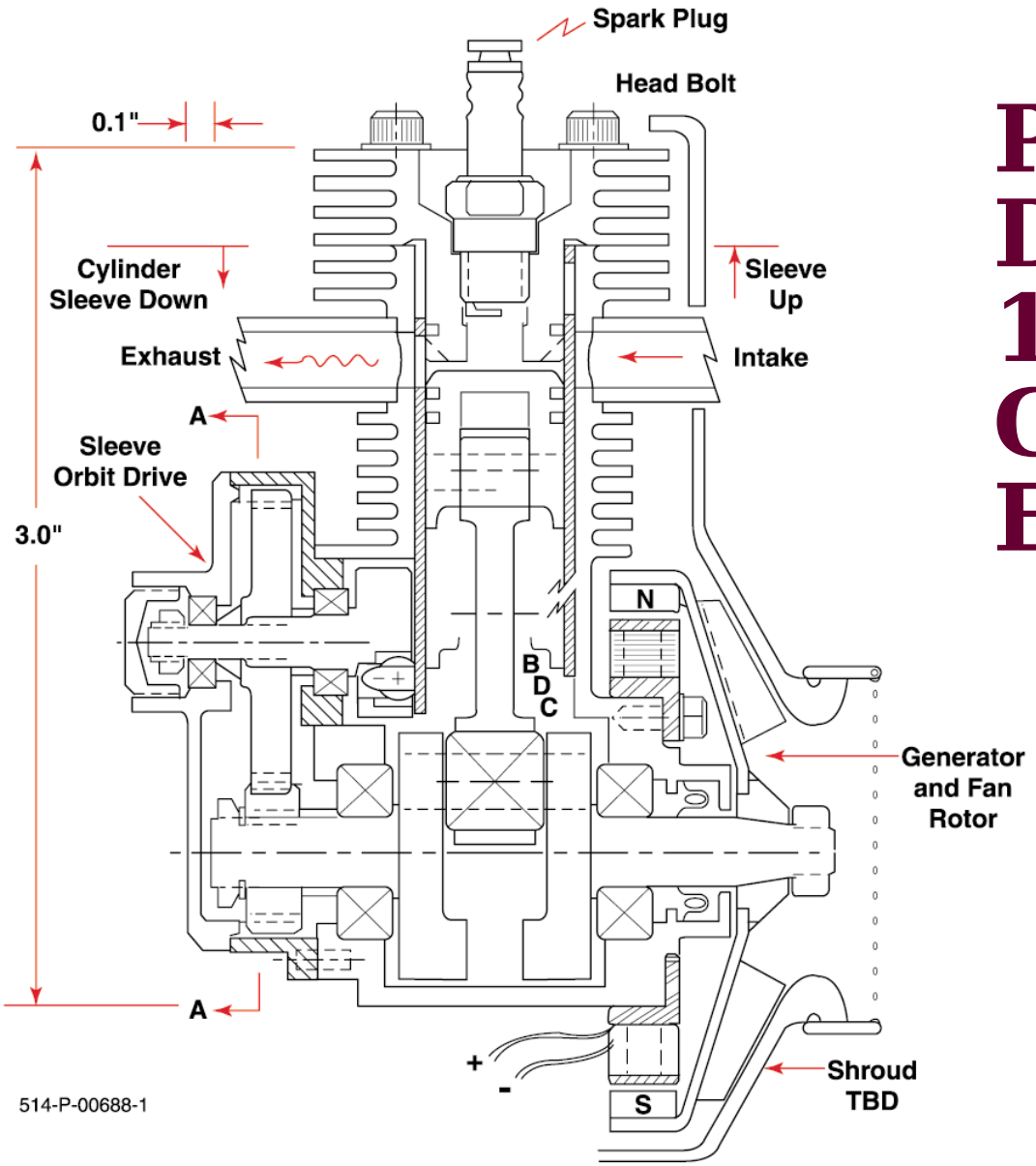
Palm Power Engine

- **Objectives**
  - 25W at 48,000 rpm
  - 1/4 in. bore and stroke
  - 4-cycle sleeve valve
  - JP-8 fuel with electric hea
- **Very conservative loadings**
  - Low piston speed, 1,000 fpm
  - Low working pressure, 90 psi bmep

Foster-Miller 20W Micro-



- 70g dry weight with large intake and exhaust silencers
- 25 percent efficiency for 3,000 Whr/kg of JP-8 fuel
- 4 cycle piston engine with smart glow plug ignition
- 12V brushless alternator/starter and starting battery



Preliminary Design of 100W Generator Engine

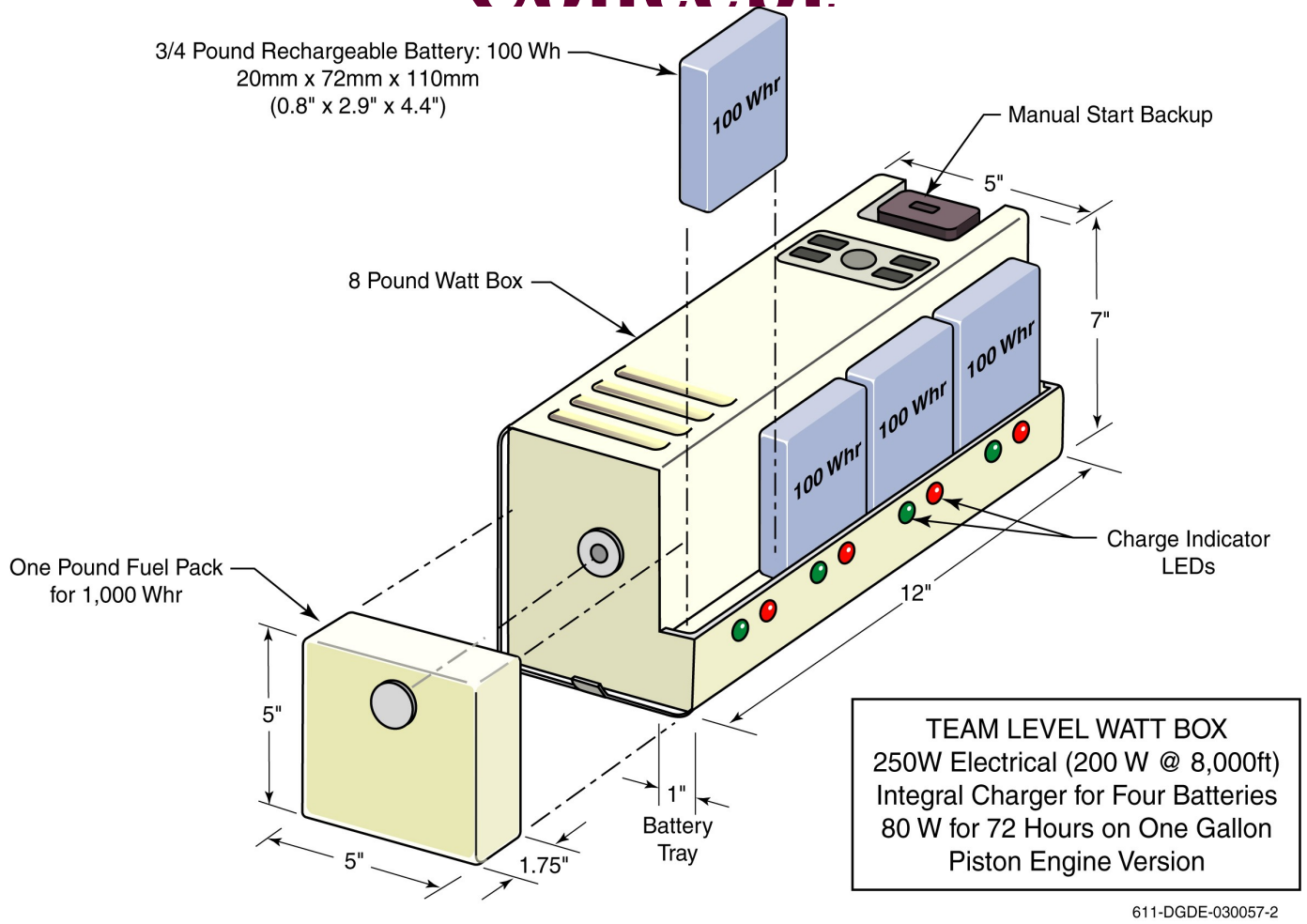
- bore = stroke = 0.5”
- displacement: 0.1 cu. in.
- speed: 22,000 rpm
- piston speed: 1,800 fpm
- bmep: 90 psi
- power: 0.24 hp, 175W

Some 100W Power Candidates

Speculations

Type	Fuel	Efficiency (%)	Fuel for 100 hr (kg)	Equipment Weight for 100W (w/o fuel and tankage) (kg)	Specific Power (W/kg)
Spark, 4-cycle PM Alternator (FMI-Concept)	JP-8	25	3.7	1.2	83
Spark, 2-cycle PM Alternator (D-Star prototype)	JP-8	17	5.5	1.0	100
H_2 Fuel Cell (Ball x 2/3)	H2	45	16.7	2.5	40
Methanol Fuel Cell (Direct)	Methanol	20	10.2	5?	20
Ref: Honda 1000W Scaled to 1/10	Gasoline	25	3.7	1.3	77

Team Level Battery Charger Concept



Prospectus: Much Smaller Spark Ignition Engines

- Relatively lighter
- Similar in efficiency
- Same stresses, velocities and bearing loads
- Easier to cool
- Higher cyclic fatigue considerations
- Proportionately quieter
- More likely to run well on JP-8 or kerosene
- Necessary technology already mass produced